Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE APPLICATION OF COLLOID CHEMISTRY TO THE FILTER-PRESSING OF SEWAGE SLUDGE[1]

By John Arthur Wilson, Wm. R. Copeland and Henry Mills Heisig[2]

The viewpoint of modern colloid chemistry is the logical one from which to attack the basic problems of sewage disposal because the solid matter of the average city sewage is chiefly an agglomeration of extremely complex bodies in the colloidal state. The fundamental object of most systems of sewage disposal is to separate these bodies from the water, and this is primarily a problem of colloid chemistry.

By colloid chemistry we mean simply the chemistry of substances having a very large specific surface (surface area per unit weight), a condition now referred to as the colloidal state. The properties of the surfaces of a body are so different from those of the main mass that any great increase in specific surface, as by repeated subdivision, results in a complete change of properties of the substance. This necessitates a change in the method of classifying substances according to properties when they have been reduced to the colloidal state.

One of the reasons for the tremendous success attending the application of colloid chemistry to industrial problems is that substances of widely different chemical constitution assume many important properties in common when in the colloidal state. The value of this fact will be apparent in sewage disposal where it is necessary to deal with innumerable substances so complex as to make successful treatment by the older conceptions of chemistry practically impossible.

The colloidal matter of sewage can be divided into two general classes: the *dispersoids* and the organized *jellies.* The dispersoids consist of extremely finely divided substances, called the *disperse*

---

[1] Presented at the Cleveland Convention, June 9, 1921. Discussion is invited and should be sent to the Editor.

[2] Sewerage Testing Station, Milwaukee, Wis.

phase, distributed throughout the water, which is called the *dispersion medium.* The disperse phase is so finely divided that the particles can be seen only with the aid of the ultramicroscope. But the jellies can be seen with the naked eye in the form of protein and cellulose fibers, tissues, hair, etc. The great specific surface of the dispersoids is due to the fineness of subdivision of the disperse phase, but that of the jellies is due to the internal arrangement of the atoms, which form a three-dimension network with interstices sufficiently large to permit the passage of water and the simpler molecules. One marked distinction between the two classes is that the dispersoids behave like a solution of the colloidal matter in water and the jellies like a solution of water in the colloidal matter.

The surfaces of these colloidal bodies possess electrical charges which tend to prevent their separation from the water, and the more so the greater the value of the charge. Our basic problem is thus to reduce the value of this electrical charge to a minimum.

The most effective means of lowering the value of the electrical charge on colloids are to alter the acidity of the solution in the proper direction or to add a substance carrying a sufficiently high electrical charge of sign opposite to that on the colloid.

In many dispersoids the disperse phase is positively charged in acid solution, but as more and more alkali is added the value of the charge is gradually reduced to zero, the *isoelectric point* of the colloid, which then coagulates and settles out. But now, if still more alkali is added, the coagulated colloid may take on a negative electrical charge and redissolve. Jellies, on the other hand, swell, or increase in volume, in acid solution by absorbing water and are then positively charged, but if increasing amounts of alkali be added, the jelly shrinks, giving up its absorbed water until, at its isoelectric point, the amount of absorbed water reaches a minimum. When the alkalinity is further increased, the jelly swells again and becomes negatively charged. The electrical charges can also be reduced by adding other colloids of opposite sign or polyvalent ions, such as phosphate for positively charged colloids and chromium or aluminum for negatively charged ones; but here too the addition of an excess of the coagulating agent may result merely in changing the sign and preventing coagulation.

At the Milwaukee Sewerage Testing Station the raw sewage is treated by the activated sludge process, the molecular mechanism of which is still a matter of speculation, although it possibly involves the formation of new colloidal bodies of opposite charge to that on the unchanged colloidal matter followed by coprecipitation of the oppositely charged bodies. The sludge obtained from this process, however, is not at its isoelectric point, but is negatively charged, and is therefore not in the best condition for filter-pressing.

The experiments reported in this paper form part of a larger work undertaken for the purpose of finding the average isoelectric point of the sludge and determining the conditions best suited for its dehydration.

Experimental. The laboratory experiments which proved most fruitful consisted in measuring the effect of a change of reaction of the sludge upon its rate of filtration. The apparatus consisted of a high vacuum pump connected to twenty filter flasks fitted with Buechner funnels. In each test twenty identical samples of sludge were treated differently, all were thrown onto filters at the same time, the rates of filtration were noted, and the final reaction of the filtrate determined. As soon as each sample was completely filtered, the flask was cut off from the main line so as not to reduce the vacuum on the others. In each preliminary investigation the series of twenty covered a wide range of treatment, but in the later work the procedure was refined by confining the series to a comparatively narrow range covering the critical points.

Method of recording acidity. It has been generally recognized for some years that the active constituent of all acids is hydrogen ion and that the activities of acid solutions can be represented quantitatively only in terms of the hydrogen-ion concentration. Likewise the active constituent of all alkalies is hydroxide ion. Since hydrogen ion and hydroxide ion unite to form water, there is a definite reciprocal relationship existing between the concentrations of these two ions in all aqueous solutions such that the value of one determines the other. In fact, the product of these two concentrations is constant, whatever the acidity or alkalinity of the solution. For this reason it is possible to record hydroxide-ion concentration in terms of hydrogen-ion concentration, making one scale do for both acid and alkaline solutions. But this gives a working range of hydrogen-ion concentration of from about ten moles to one quadrillionth of one mole per liter. (One mole of hydrogen ion is 1 gram; one mole of hydroxide ion 17 grams.) For the purpose of record it has consequently been found advisable to use the logarithms of these values, reducing the range to 16 units.

The term pH is now commonly applied to the logarithm of the hydrogen-ion concentration, with change of sign. A pH value of 1 means 0.1 mole per liter; a pH value of 2 means 0.01 mole; a pH of 3 means 0.001 mole, etc. A pH value of 7 indicates a neutral solution; one less than 7 an acid one; and one greater than 7 an alkaline one.

Effect of change of acidity. In the first series of experiments 90-cc. portions of sludge were treated with 10 cc. of standard sulfuric acid or sodium hydroxide in order to give a wide range of pH values. The rates of filtration were noted and the pH values of the filtrates determined. With some modifications this procedure was continued daily for months in order to cover all kinds of sludge and to discover the extreme variations to be expected. It is remarkable that the sludge showed very little variation in a number of important properties. The pH value of the sludge itself varied only from 7.7 to 8.3, with an average of about 8.0. The addition of alkali, such as lime or lye, invariably increased the time of filtration. The average isoelectric point was confined to the rather narrow limits 2.8 to 3.6. The effect of change of pH value is shown graphically in the lower curve in figure 1, which is typical of most of the sludges encountered. It will be noted that the addition of very little alkali has a very powerful effect in retarding the filtra-

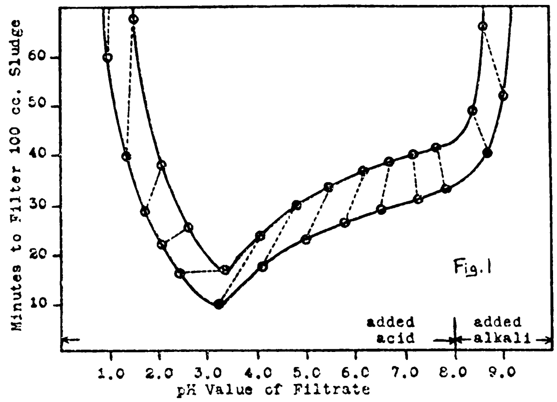

FIG. 1. Lower curve is for samples filtered 15 minutes after treating with acid or alkali; upper curve for samples filtered 24 hours after treating. Dotted lines connect the points for samples treated exactly alike; the lower curve shifts toward the upper one during the 24-hour period, the individual points moving in the directions indicated by the dotted lines.

tion. The addition of sulfuric acid continues to increase the rate of filtration until a pH value of 3.2 is reached, after which further addition of acid has a marked retarding effect. By adding the proper amount of acid the rate of filtration was often increased by about 400 per cent and considerably more when the sludge was not in good condition. In every case the clearest filtrates were obtained from the samples having the greatest rate of filtration.

Although the average isoelectric point was practically the same for all types of sludge, the actual time required for the filtering of a fixed quantity was very variable, even at the same pH value. With two samples at the same pH values and having the same percentage of solid matter, one might require twice as long to filter as the other. Much study has been given to this difference in condition of the sludges and it has been found that at least two factors have a bearing on it; one the temperature of the raw sewage at the time of aeration and the other the extent to which decomposition has taken place after the aeration process. When the sewage is aerated at a temperature of 60° F. or over, the resulting sludge is in much better condition for filter-pressing than when the sewage is aerated at 40° or under. The effect of decomposition after the aeration process is also a most important one and is responsible for peculiar time changes with which we have been confronted in our work.

Time changes in the condition of sludge. Dissolved materials diffuse into jellies comparatively slowly and it was apparent from the start that the pH value of the sludge would slowly change for some time after the addition of acid or alkali due to their slow absorption by by the jellies. Accompanying this drift in pH value one would naturally expect a change in the rate of filtration. In order to study the effect of this drift, we usually set up the series in duplicate, filtering one set immediately after treating and the other 24 hours later. A pair of such duplicates usually gave the results shown in figure 1. At times, however, the results were like those shown in figure 2, and it was at first thought that the difference might have been due to the infrequent dumping of large amounts of an unusual type of industrial waste. It appears at present as though the effect is due rather to decomposition of the sludge after the aeration process. A sample of sludge which had given a pair of curves like those in figure 1 was kept in the warm air of the laboratory for 24 hours and then the experiment was repeated, but this time it gave a set of curves like those in figure 2.

While the difference between the two curves in figure 1 is probably due partly to the slow absorption of acid or alkali by the jellies, it is probably due in a greater measure to slow decomposition. This is more obviously true for the curves in figure 2, which seems to indicate that this decomposition proceeds at the greatest rate at a pH value of about 5.3.

In the upper curve in figure 2, the steepness of the slopes either side of the isoelectric point shows that decomposition makes the rate of filtration much more sensitive to changes in pH value. This introduces a serious difficulty when dealing with concentrated sludges during the winter time when the aeration of the sewage takes place at a low temperature. Because of the danger of further decomposition, such sludge must be filtered as soon as possible after treating. But the drift in pH value of concentrated sludge is considerable and the rate of filtration of this sludge is very sensitive to changes in pH value. The optimum range is so narrow and the drift so great that whatever the initial pH value, the sludge would not remain within the optimum range for more than a fraction of the time required for pressing. But by diluting the sludge before acidifying, the extent of the drift in pH value is reduced because the sludge then has a greater reservoir of acid from which to draw. We have actually demonstrated that the time of filtration of such a sludge can be materially reduced by diluting with an equal volume of water

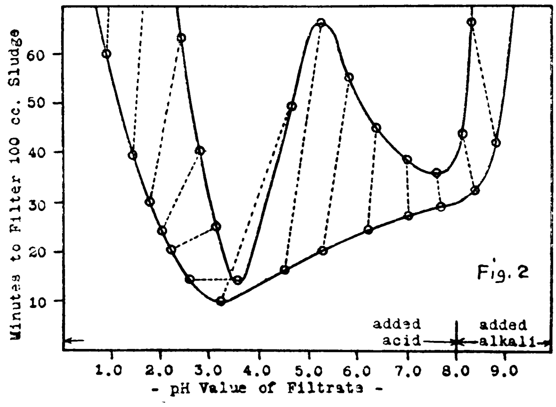

FIG. 2. Same as figure 1 except for an initial difference in the character of the sludge. The peculiar maximum in the 24-hour curve appears to be due to products of putrefaction.

before treating, even though more than twice as much water must then pass through the filters. On the other hand, diluting a sludge which is in good condition may increase the time of filtration by increasing the amount of work involved in expelling water from the sludge.

The curves in both figures 1 and 2 show how to acidify a sample of sludge to get the best results. The isoelectric point of the sludge which has stood 24 hours is always slightly higher than that which has been filtered at once, but corresponds to a treatment which gave a pH value slightly lower than the isoelectric point in the series filtered at once. This treatment is the one that will give the best results in practice, where several hours may be required for each pressing. It will be noted from the curves that, while the pH value increases, the time required to filter a fixed quantity remains practically constant.

Unless some means is devised to counteract the effect of low temperature upon the aeration process, the design of the plant and system of operation are likely to be seriously complicated, since a much more extensive filter-pressing system would be required whenever the temperature of the raw sewage dropped appreciably. The cost of heating 65,000,000 gallons of raw sewage daily would seem to be prohibitive. Although control of the pH value is a step in the right direction, it will not entirely bridge the gap between summer and winter sludge. It appeared possible, however, that this might be accomplished by the addition of substances carrying a sufficiently high positive electrical charge.

Action of salts yielding polyvalent ions. Because the sludge carries a negative electrical charge it was evident that good results could be expected only from positively charged polyvalent ions. It was then demonstrated that sodium phosphate greatly retards the rate of filtration while aluminum and chromium sulfates accelerate it, provided an excess is not used. These salts hydrolyze readily and introduce complications by altering the pH value, but this difficulty was overcome by adding an amount of salt based upon the percentage of solid matter and then regulating the pH value with acid or alkali. The increase in rate of filtration brought about by the use of aluminum or chromium sulfate at optimum acidity was much greater than could be obtained by acid alone. Where acid alone increased the rate of filtration by 400 per cent, the proper use of aluminum sulfate and sulfuric acid gave an increase of 900 per cent, which will nearly, if not quite, overcome the difference between summer and winter sludge.

Figure 3 shows a typical set of curves obtained in the laboratory on the same sludge with and without aluminum sulfate. It is interesting to note that the aluminum sulfate actually retards filtration on the acid side of the isoelectric point, where the sludge is positively charged. Another interesting fact is that the aluminum sulfate is most effective at a pH value of about 4.3. This is not surprising in view of the fact that the isoelectric point of aluminum hydroxide lies at about 7.5 and that of the sludge at about 3.0. At a pH value of 7.5 the aluminum hydroxide would not carry any electrical charge and would consequently be of little value in coagulating the negatively charged sludge. Somewhere between 3.0 and 7.5 the negative charge on the sludge must be equivalent to the positive charge on the aluminum complex, and this point appears to have been about 4.3 for the conditions of our experiment. The curves show the time required to filter 500-cc. samples of treated sludge. By using larger samples in these tests we were able to make more accurate studies of the change of rate of filtration with time.

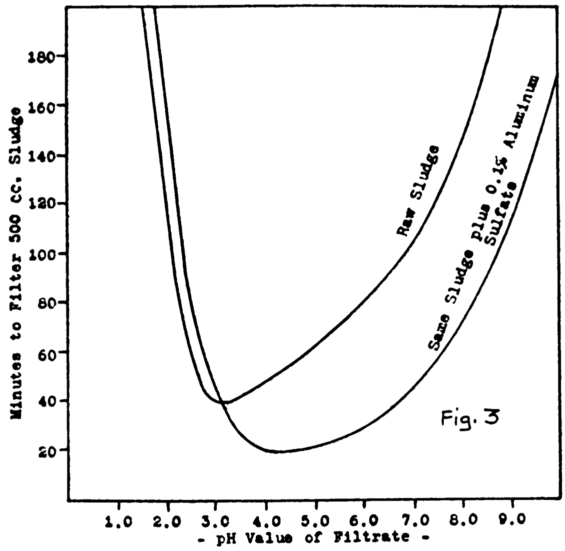

FIG. 3. Showing how the addition of aluminum sulfate before treating with acid or alkali changes speed of filtration.

In the experiments with aluminum sulfate, it was customary to set up each series in duplicate, as in the experiments with acid, filtering one series 15 minutes after treating and the other 24 hours later. Time changes were found similar to those shown in figures 1 and 2, which indicates that decomposition of the sludge proceeds, even in the presence of aluminum sulfate. Studies are now being made of the putrefaction of sludge and its relation to the aeration process.

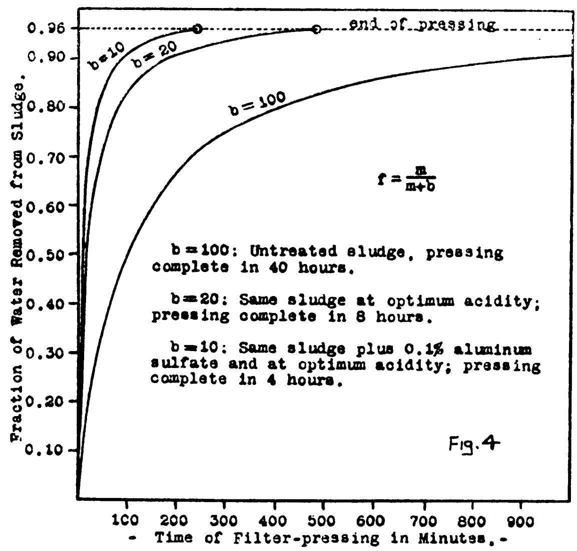

FIG. 4. Showing how the rate of filtration decreases with time, but according to the method of treating the sludge.

Chromic sulfate gave results very similar to those of aluminum sulfate. Ferrous sulfate, on the other hand, showed no improvement over acid alone. The lesser effect of this salt is, of course, easily explained by the fact that the ferrous ion has only a double electrical charge, whereas the chromium and aluminum ions carry triple charges in acid solution.

Time changes in rate of filtration. In filter-pressing, it had always been noted that the rate of filtering continued to fall throughout the pressing. Readings were taken at frequent intervals on an experimental plate press and the fraction of water removed was plotted against the time in minutes. This was repeated for sludges of different types and treatments, but in every case the curve obtained was an hyperbola of the familiar die-away type and corresponded to the formula $f = m/(m + b)$, where f is the fraction of total water removed, m the number of minutes which have elapsed since the start of the pressing, and b a constant depending upon many different factors. Keeping the press, filter bags, quantity of sludge, and percent of solid matter in the sludge constant, then b becomes an index of the condition of the sludge, which will vary with the treatment.

TABLE 1

Comparative data on large scale pressings and laboratory tests

	SLUDGE 1	SLUDGE 2	SLUDGE 3	SLUDGE 4
Gallons of sludge pressed	2871	2673	3193	3228
Percent water in sludge	98.98	98.83	99.06	98.95
pH value of sludge	7.4	7.7	7.4	7.6
Cubic centimeters of sulfuric acid added per gallon	none	2.50	1.04	2.65
Grams of aluminum sulfate added per gallon	none	none	3.15	none
Initial pH value of treated sludge	7.4	3.9	4.4	2.7
Final pH value of treated sludge	7.7	6.0	6.6	6.0
Pounds of cake produced	1407	1118	1275	1240
Percent water in cake	84.4	81.4	82.0	81.1
Hours required for pressing	23.8	6.0	5.3	6.4
Hours required to filter 500-cc. treated sample in laboratory	0.62	0.15	0.083	0.15
Ratio of time consumed in large scale test to time consumed in laboratory test	38	40	64	43

Note: Sludges 2, 3, and 4 left the filter bags clean and in good shape for further pressing, but sludge 1 left them so gummed up that they could not be used again without washing.

Figure 4 shows the effect of aluminum sulfate and of optimum acidity upon the change of rate of filtration as well as upon the value of b. In this case the pressing is taken as complete when 96% of the water has been removed.

According to the formula, for any fixed value of f, m is directly proportional to b. This would seem to justify our method of comparing sludges by filtering equal quantities. If it takes twice as long to filter 100 cc. of sludge A as of sludge B, we should expect it also to take twice as long to filter 100 gallons of sludge A as of sludge B. In other words, whatever the quantity of sludge to be filtered under fixed conditions, the percentage increase or decrease in time required caused by a given treatment should be the same whether the test be made on a small scale in the laboratory or on a large scale in the plant, provided, of course, that secondary disturbing influences are excluded.

At the time of writing this paper, we had just begun to apply the laboratory data to large scale pressings and fortunately there is sufficient data now available to show that the theory that the laboratory tests could be applied almost quantitatively to large scale work was not unsound. This is clearly shown in the data given in table 1. All large scale pressings were made on the same press and the laboratory tests on Buechner funnels and filter paper as nearly alike as possible. Where 0.62 hours was required to filter a 500-cc. sample of untreated sludge in the laboratory, it took 23.8 hours to press 2871 gallons. of this same sludge. Where it required only 0.15 hour to filter 500 cc. of treated sludge in the laboratory, it took 6 hours to press 2673 gallons of this same sludge. The laboratory test showed that treating with acid reduced the time required to filter to about one-fourth and this ratio was also found in the large scale pressing. The ratio of the time consumed in the large scale test to time consumed in laboratory test is apparently about 40. There is an apparent discrepancy in the case of the sludge treated with aluminum sulfate, but this is probably due to the fact that the laboratory samples should have been larger as it is difficult to estimate the time of filtration more closely than to one minute, which is a large fraction of the approximately five minutes required for filtration in the laboratory test. The laboratory samples should be larger for another reason also; the drift in pH value in a 6-hour pressing in much greater than in the laboratory tests and will have an effect upon the ratio found.

More experiments both in the laboratory and plant will be carried out as rapidly as possible, but we believe that enough has been done to prove the enormous importance of colloid chemistry in problems of sewage disposal and the necessity for controlling the pH value of sludge to be pressed efficiently. The entire subject will probably be found to apply with equal force in problems of water filtration.